PHYSA: 14448 Model 3Gsc pp. 1–15 (col. fig: NIL)

ARTICLE IN PRESS

Physica A xx (xxxx) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Physica A

journal homepage: www.elsevier.com/locate/physa



# The related congestion failure estimating methodology and model in transportation networks

PengCheng Yuan *, ZhiCai Juan

*Antai College of Economics & Management, Shanghai Jiaotong University, Shanghai, 200052, PR China*

## HIGHLIGHTS

- We use the copula theory to estimate the related congestion failure in transportation networks.
- A new model of congestion failure is constructed to evaluate the performance of the dynamic transportation system.
- Empirical studies show that the proposed method and model are reasonable.

ARTICLE INFO

*Article history:*
Received 30 October 2012
Received in revised form 2 May 2013
Available online xxxx

*Keywords:*
Travel time related
Reliability
Copula
Congestion failure
Alternate update

ABSTRACT

Previous works about the probability-based transportation networks evaluation method mainly focus on the static reliability evaluation, they ascribe the stochastic of the travel time to the external long time factors (the traffic supply or the traffic demand). Under this situation, the link's travel time related relationship can be inferred, and it is efficacious for planners or engineers to make a decision for a long time. Even though some evaluation methodologies about transportation networks' real-time travel time reliability has been presented, these works assume that the link's travel time is independent. In this paper we relax this assumption. Using the Gauss copula theory, we present a new method to evaluate the transportation networks' real-time travel time reliability. The results show that it will overestimate the route or the networks' travel time reliability when not considering the link's travel time. Not only that, we deep the static reliability evaluation model to the dynamic, and present the link and net congestion failure evaluation model. Estimations from the model are compared to field-measured data. It shows that, under the error interval $\pm 2$ times, the link congestion failure model accuracy rate is above 90.3%, under the error interval $\pm 0.05$; the net congestion failure model accuracy rate is above 95%.



## 1. Introduction

With the development of urban transportation systems, the scale of urban transportation networks grows larger and more complex [1–6], and traffic demand and supply grow more rapidly at the same time. Especially, with the rapid development of electronic information and communication technologies, there is great potential in the application of advanced technologies to relieve traffic congestion and improve the network reliability. Nowadays, most cities in the world have established driver information systems to provide information to drivers. Most of the information is about road congestion states (smooth, congested and blocked) or the predicted travel time to a given destination. Although this determined information is widely used in cities of the world nowadays and has been proved be efficacious in relieving traffic congestion [7–9], many other researches tried to find out a better evaluation method to evaluate the performance of

* Corresponding author. Tel.: +86 02152301396.
*E-mail addresses:* danis_cx@126.com (P.C. Yuan), zcjuan@sjtu.edu.cn (Z.C. Juan).

0378-4371/$ – see front matter © 2013 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.physa.2013.05.022

Please cite this article in press as: P.C. Yuan, Z.C. Juan, The related congestion failure estimating methodology and model in transportation networks, Physica A (2013), http://dx.doi.org/10.1016/j.physa.2013.05.022

the traffic system. Inspired by these ideas, as a result we believe that perhaps the probability based traffic information could be a useful complement for travelers. But, what probability based traffic information can be provided by the information providers? How will it be evaluated? Till now, we could only find reliability based evaluation indicators/models for transportation networks. Though these indicators/models are very important for planners or engineers, they cannot give a deep impression for travelers. In this paper, we present a new indicator/model, called congestion failure, to evaluate transportation networks. We also give an analytical travel time reliability methodology which considers the link travel time to be related.

Previous works about probability based evaluation methods mainly focus on the reliability of transportation networks, which include transportation network reliability definitions [10,11], evaluation methods [12–14] and the impacts of reliability [15–18]. All of these studies no longer see the transportation system as determined, but stochastic [3,19,20]. It should be described by probability based indicators. It is obvious that this description is more realistic and efficacious. Travel time reliability is the most important indicator in all of these indicators. But there are some limits to these works. First, previous studies display that the stochastic of the travel time is caused by exogenous factors such as traffic demand or/and traffic supply (the capacity) [21,22]. It is easy to be understood according to the travel time function. For example, the BPR function ($T = T_0\left[1 + \alpha\,(X_a/C_a)^{\beta}\right]$), for which the travel time is a function about $X_a$ and $C_a$ ($X_a$ is the volume of link $a$, and $C_a$ is the capacity of link $a$.), $X_a$ is a random variation because of the assumption that the traffic demand is random, the $C_a$ is a random variation because of the random link damage or parking. So the travel time is a random variation because $X_a$ or/and $C_a$ is/are random. Second, previous studies about travel time reliability are static models, they have not uncovered the reliability changing with time. We believe the previous works about travel time reliability analysis are meaningful for long-time transportation system planning, designing or optimization, but it is not so efficacious for travelers, because they need real-time information. Ref. [23] applied Monte Carlo methods to estimate the distribution of the whole transportation networks' travel time distribution under the assumption of the Normal distribution of traffic supply; Ref. [24] derived the travel time distribution by an analytic method under the assumption of the Poisson distribution of the traffic demand. Then Ref. [22] derived the travel time distribution by considering that both traffic demand and capacity are stochastic. Different from previous views, in this paper, we only consider the travel time reliability in a short time, the traffic demand and the capacity are determined in this situation, and the stochastic of the travel time is only caused by endogenous factors.

The objective of this paper is to supply a new method to evaluate the transportation network travel time reliability when considering that link travel times are related, and then, based on it, constructing a related congestion failure model to evaluate the stochastic traffic system. Much useful information will be obtained by the model. For example, how many times someone will encounter congestion on a route in a time interval $t$? What is the probability the network will become congested after time $t$? We think the information is very valuable and useful for travelers.

There are two main innovation points in this paper. First, we use the copula theory to solve the route and network travel time reliability evaluation when considering that link travel times are related. The copula theory is more used in financial fields, but rarely be used in transportation areas. In this paper, we construct the Gauss copula function to connect the union travel time probability density function and the marginal travel time probability density function. To the best of our knowledge, it is the first time the related reliability evaluation problem has been solved using this method. Second, different from previous evaluation indices, we use congestion failure to evaluate the performance of the dynamic transportation system, this method can help us get that congestion occurs times in a given time interval $t$, and can also be used to forecast the link state after time $t$. All of these would be useful but were rarely involved in previous researches.

The paper is organized as follows. After the introduction, Section 2 describes the travel time and congestion failure definitions and some assumptions. Section 3 provides an assessment methodology to evaluate the travel time reliability when considering that link travel times are related. Section 4 introduces the traffic congestion failure model, which includes link and net congestion failure. Some results and the validation of the model will be analyzed in Section 5. Section 6 provides some concluding remarks and a discussion of future research.

## 2. Definitions and assumptions

### 2.1. Travel time reliability definition

In this paper we adopt the travel time reliability definition presented by Ref. [12] and Ref. [25]. The travel time reliability of link $a$ is defined by a probability that a trip can be made successfully within a specified interval of time. It can be written as

$$R_a = p(t_a^0 < T_a < \lambda_{t_a}^0) \quad \forall a \in A \tag{1}$$

where $A$ is the link set; $R_a$ is the reliability of link $a$; $T_a$ is the travel time on link $a$, it is a random variable; $t_a^0$ is the free travel time of link $a$; $\lambda$ is a constant value.

Similar to the link travel time reliability definition, route travel time reliability can be written as

$$R_k = p(t_k^0 < T_k < \lambda_{t_k}^0) \quad t_k^0 = \sum_{k\in K} t_a^0 \delta_{a,k} \quad \forall a \in A\; k \in K \tag{2}$$